SPG

21. November 2019
Universität Bern

Lemaître and the Astronomical Environment of the 1920s

Harry Nussbaumer
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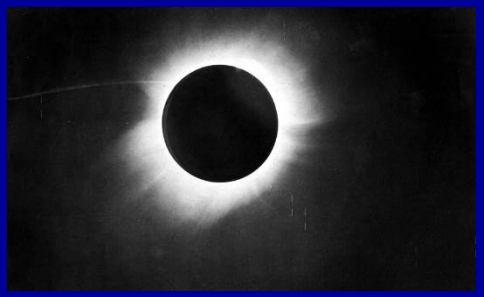
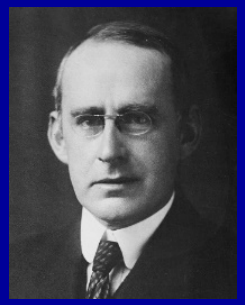
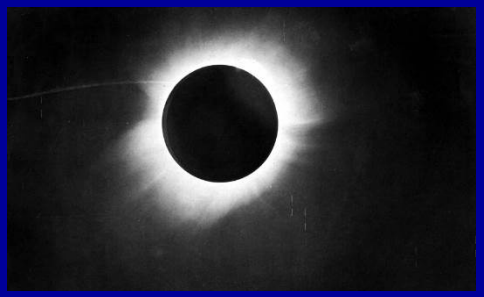
ETH Zurich (Switzerland)

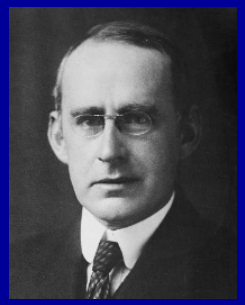




From the report of Sir Arthur Eddington on the May 1919 solar eclipse expedition to the island of Principe (west coast of Africa).

Lemaître 1927





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Lemaître 1927

Content of this talk

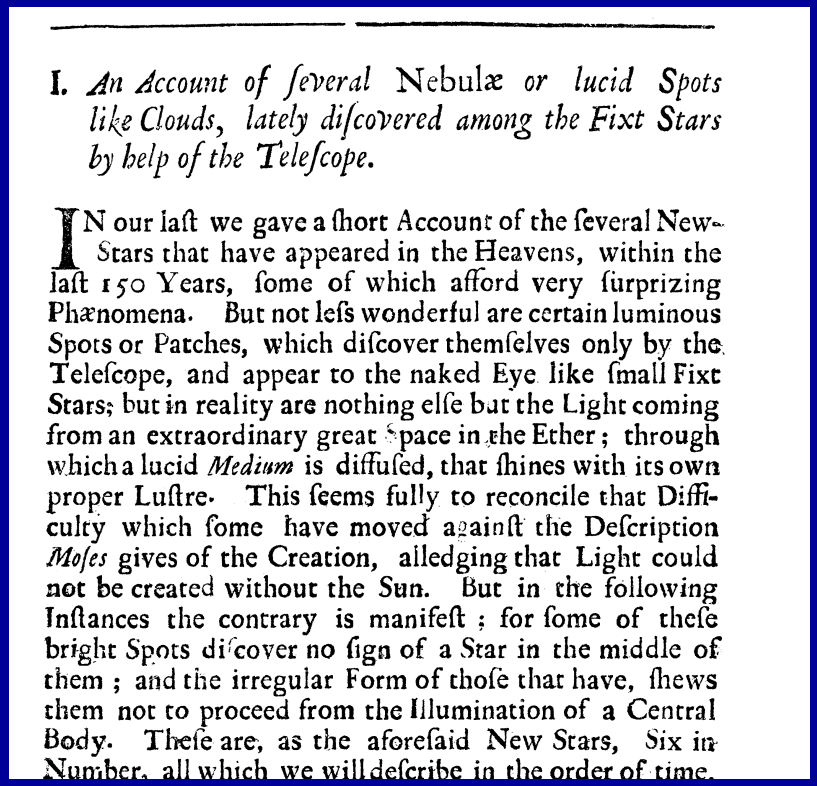
1. Discovery of the nebulae and the place they took in cosmology since the 17th century.
2. The beginning of modern cosmology with Einstein and de Sitter.
3. Lemaître's entry into cosmology, and the discovery of the expanding Universe in 1927.
4. Astronomy in the 1920s: What were the open questions?
5. Constructing a myth.
6. Lemaître's impact on cosmology.

Nebulae enter astronomy

Al Sufi (903-986), persian astronomer.
Book of Fixed Stars, with illustrations, written in Arabic ≈964:
A cloudlike spot in Andromeda designed as «*a little cloud*».
(Italian parchment 1428)

Simon Marius (1573-1624).
1612. A nebulosity in *Mundus Jovialis*.
First telescopic observation:
Light of a candle seen through a horn.

Halley defends Moses' description of the Creation



I. *An Account of ſeveral* Nebulæ *or lucid Spots like Clouds, lately diſcovered among the Fixt Stars by help of the Teleſcope.*

IN our laſt we gave a ſhort Account of the ſeveral New Stars that have appeared in the Heavens, within the laſt 150 Years, ſome of which afford very ſurprizing Phænomena. But not leſs wonderful are certain luminous Spots or Patches, which diſcover themſelves only by the Teleſcope, and appear to the naked Eye like ſmall Fixt Stars; but in reality are nothing elſe but the Light coming from an extraordinary great Space in the Ether; through which a lucid *Medium* is diffuſed, that ſhines with its own proper Luſtre. This ſeems fully to reconcile that Difficulty which ſome have moved againſt the Deſcription *Moſes* gives of the Creation, alledging that Light could not be created without the Sun. But in the following Inſtances the contrary is manifeſt; for ſome of theſe bright Spots diſcover no ſign of a Star in the middle of them; and the irregular Form of thoſe that have, ſhews them not to proceed from the Illumination of a Central Body. Theſe are, as the aforeſaid New Stars, Six in Number, all which we will deſcribe in the order of time.

1716, Edmond Halley in Phil. Trans. **29,** 390-392.
An account of several nebulae or lucid spots like clouds, lately discovered among the fixt stars by the help of the telescope.

A lucid medium that shines with its own proper lustre.
This seems fully to reconcile that Difficulty which some have moved against the Description Moses gives of the Creation, alledging that Light could not be created without the Sun.

Cosmology in the second half of the 18th century:

Nebulae as

«island universes»

Immanuel Kant (1724-1804).
1755: Allgemeine Naturgeschichte und Theorie des Himmels.

Pierre-Simon Laplace (1749-1827).
1796: Exposition du sytème du monde.

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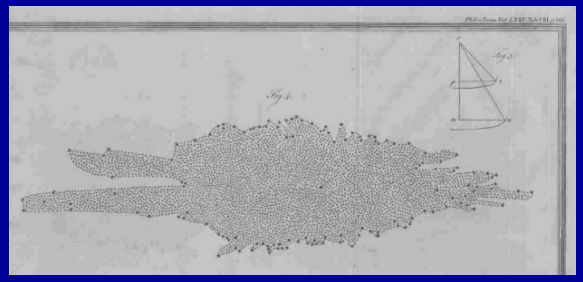
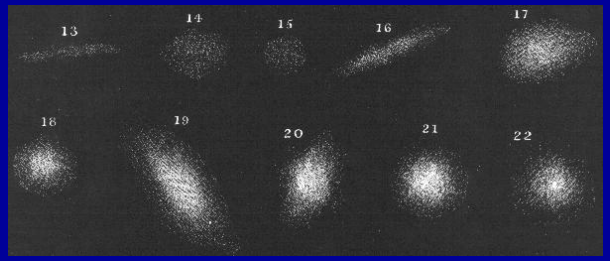


Herschel 1785: The Milky Way.



Herschel's observations of nebulae.

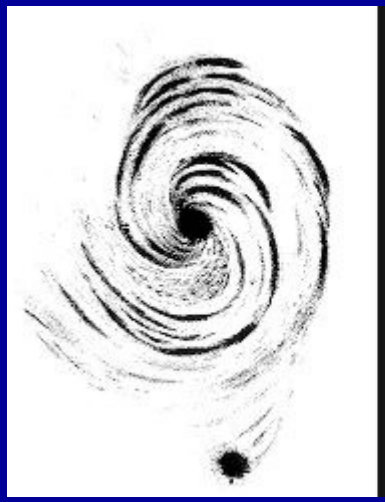
Planetary nebula NGC 1514 ruins the island unierse.

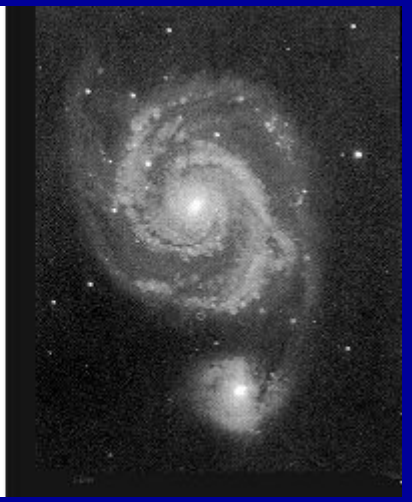
1785: these nebulae *may well outvie our milky-way in grandeu*r.

1791: Confused by a planetary nebula, he concentrates on the connection between stars and nebulae.

Cosmology in the 19th century

1845 Leviathan (72-inch, 1.83 m), Earl of Rosse.
(1917, Hooker 2.54m, Mt. Wilson)





M51: Rosse 1850 M51: moderne Foto

1845: Rosse discovers spiral nebulae

Larger telescopes, but, these nebulae, what are they?
Are they "island universes", or are they part of the Milky Way ?

Cosmology in the 19th century

Spectroscopy

H, Ca, Na, O, Mg, Fe, etc.

1814. Fraunhofer.
First high quality solar spectrum.

1859. Kirchhoff & Bunsen.
Unity of the physical Universe
Aristoteles was wrong !

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Nebular spectra. 1864, 1866: Huggins, after investigating nebular spectra:
The views about the universe change rapidly. When it comes to interpretation, it is wiser to wait and keep an open mind.

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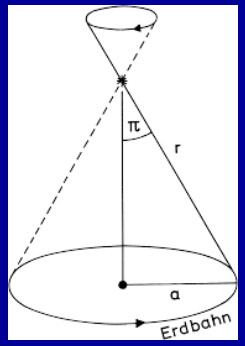
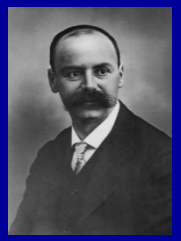
Distances to stars

In the 1830ies stellar distances were determined by
F.W. Bessel (Königsberg), 61 Cyg
F.G.W. Struve, (Pulkovo, St. Petersburg), Vega
Henderson (Edinburgh), α Centauri



Cosmology at the beginning of the 20th century

1900: Karl Schwarzschild dreams of **a non-Euclidean closed universe**.



Der Raum selbst endlich und in sich geschlossen: So müsste eine Zeit kommen, wo der Raum durchforscht wäre, wie jetzt die Erdoberfläche.
Everything will be known!
Vierteljahrsschrift der Ast. Ges, 35, 337

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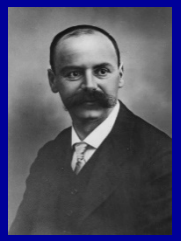

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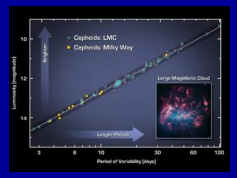
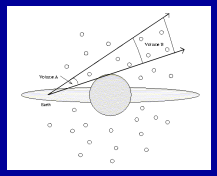
Harlow Shapley:
What is the Milky Way?
1918 Sun far from centre.
(1912 Henrietta Leavitt: cepheids, Shapley: RR Lyrae variables)

Where are the nebulae?





1908 Mount Wilson 1.5m. **The Hale.**

1920: The Great Debate.
Shapley vs Curtis:
Are nebulae part of the Milky Way?

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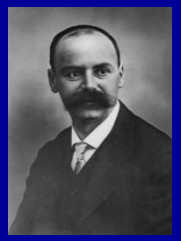

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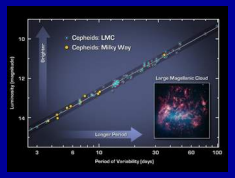

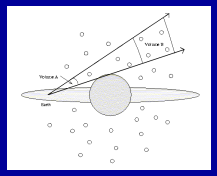

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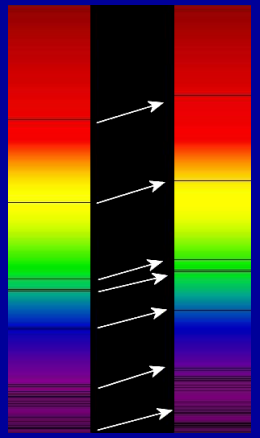
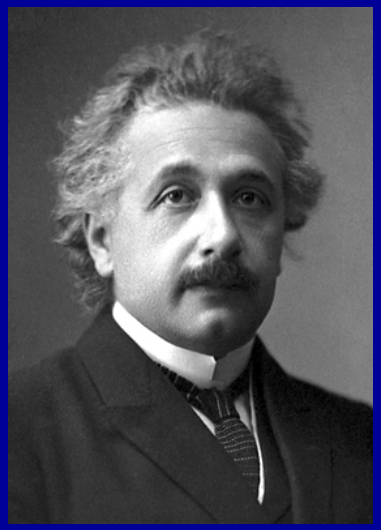
≥1912: Vesto Slipher finds in most spiral nebulae strongly redshifted spectra.
They remain an enigma up to Lemaître's explanation in 1927.



1917: The first cosmological models based on general relativity



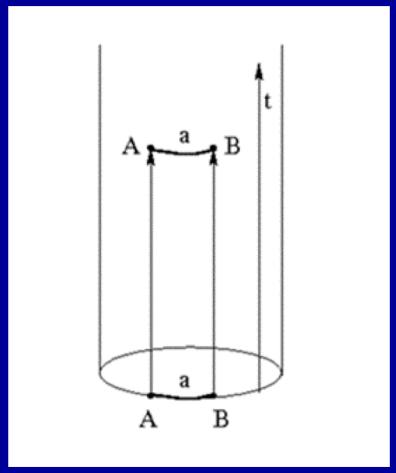
Albert Einstein (1879-1955)

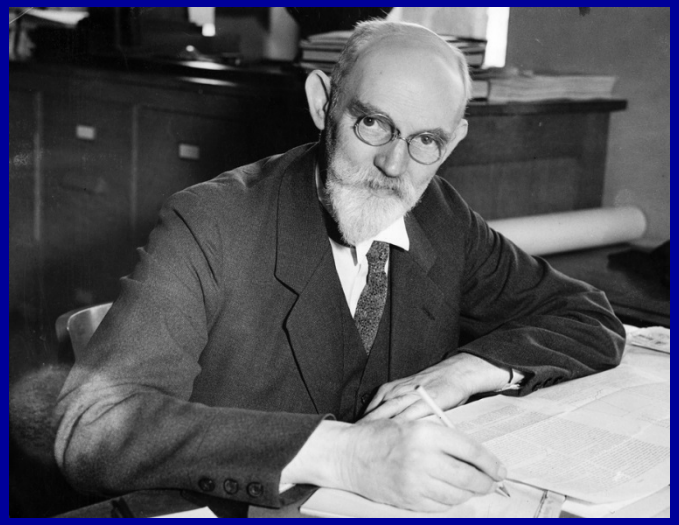
$$G_{ij} = -\kappa\left(T_{ij} - \frac{1}{2}g_{ij}T\right)$$

$$G_{ij} - \Lambda g_{ij} = -\kappa\left(T_{ij} - \frac{1}{2}g_{ij}T\right)$$

Extensively discussed among mathematicians and theoretically inclined astrophysicists.

a static and homogenous universe





Willem de Sitter (1872-1934)

$$G_{ij} - \Lambda g_{ij} = 0$$

$$\frac{\Delta\lambda}{\lambda} = f\left(\frac{r}{R}\right)$$

Up to 1930 discussed in connection with Slipher's redshifts.

Early reaction of theoreticians and observers

In Einstein's model Slipher's observed blue- and redshifts find no explanation.

De Sitter's model predicts redshifted spectra of test objects.
It provides relationships between the distance to the test object, the observed redshift, and the radius of curvature of the universe, e.g. de Sitter 1917, Friedmann 1922, Lanczos 1922, Eddington 1923, Weyl 1923, Silberstein 1924**.**

1924: First observer to bother about cosmological models and redshifts.
De Sitters Kosmologie und die Radialbewegungen der Spiralnebel. C. Wirtz, Astron.Nachr. 1924.

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A crucial obstacle was the ignorance about the structure of our wider astronomical environment.
What are the distances?

M 80
Globular cluster

Distances by Shapley known from cepheids.
(Leavitt 1912, Shapley 1918)

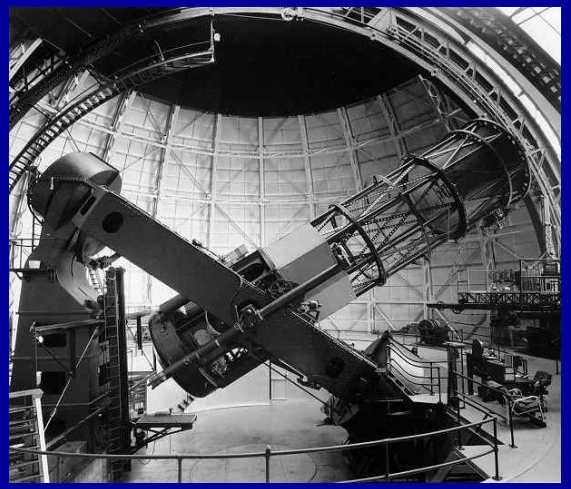
M 49
elliptical galaxy

No distance

1925: Yes, Island Universes do exist !

Die neue Epoche der Grossteleskope

1908 Mount Wilson 60-inch (1.5m). **The Hale**



1917 Mount Wilson 100-inch (2.5m). The Hooker

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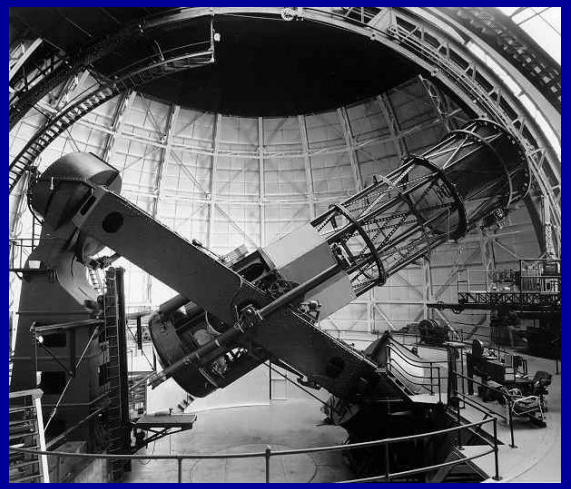

1917 Mount Wilson 100-inch (2.5m). The Hooker

1925: Edwin Hubble (1889-1953). **Finds cepheids in three spiral nebulae**

He gives for M31 and M33 a distance of approximately 285 Kpc (≈800 Kpc).

Thus, they lie far outside Shapley's size of the Milky Way.

Yes, island universes do exist !

Lemaître's way into cosmology

Georges Lemaître, born 17 July 1894, in Charleroi (Belgium).
1914-1918 in the army. Studied physics and mathematics. He studied general relativity, in particular Eddington's *The Mathematical Theory of Relativity* which had appeared in 1923.
He won a fellowship to study in England.

In parallel Lemaître had decided to become a priest. He was ordained in 1923.

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1923/24 Lemaître as research associate in **Eddington's group in Cambridge**.
Eddington (1882-1944) is an acknowleged authority in astrophysics and general relativity.

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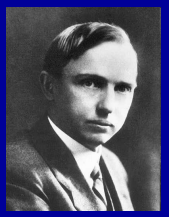


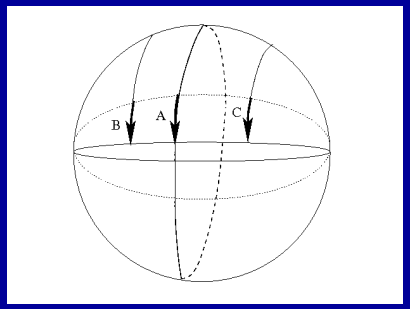
1924/25 Lemaître works in **Shapley's group at Harvard** on the theory of Cepheids.
He also registered at MIT for a doctorat on general relativity which he obtained in 1927.

In March 1925 he publishes an investigation: *A new form of de Sitter's solution*

In 1925 he travels widely in the USA (Slipher, Hubble, and others)

In July 1925 he returns to Belgium to become lecturer at the Catholic University of Louvain

1925: Lemaître uncovers de Sitter's problem

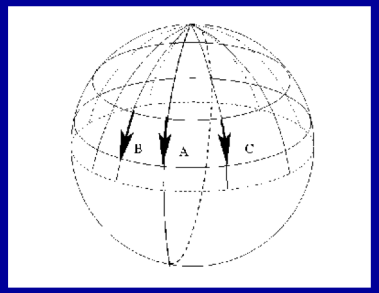


De Sitter violates the principle of homogeneity.

Note on de Sitter's universe published in J. of Math. and Phys. **4,** 188 (1925), and in Phys.Rev. **25**, Ser.II (1925) (abstract)

$$ds^2 = R^2\left(-d\chi^2 - \sin^2\chi\left(d\theta^2 + \sin^2\theta d\phi^2\right) + \cos^2\chi dt^2\right)$$

$$where \quad \chi = r/R$$



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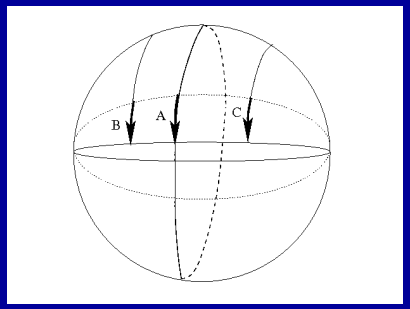

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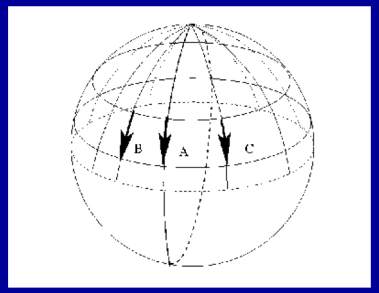
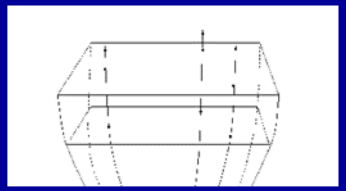


Lemaître separates space and time: $ds^2 = R^2\left[e^{\pm 2T}\left(dx^2 + dy^2 + dz^2\right) + dT^2\right]$

He finds a homogenous, flat, euclidean, non-static universe:
It might explain the receding spiral nebulae. - Lemaître rejects this model. Why?



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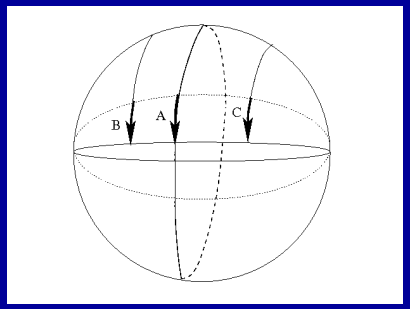

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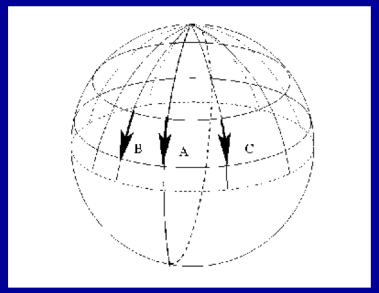

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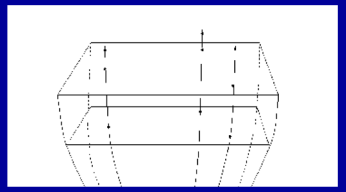


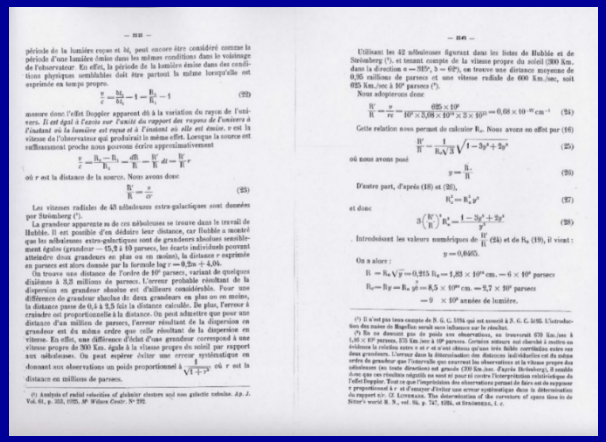
"We are led back to the Euclidean space and to the impossibility of filling up an infinite space with ***matter which cannot but be finite****… ."*

Philosophy not physics ! Thomas Aquinas?

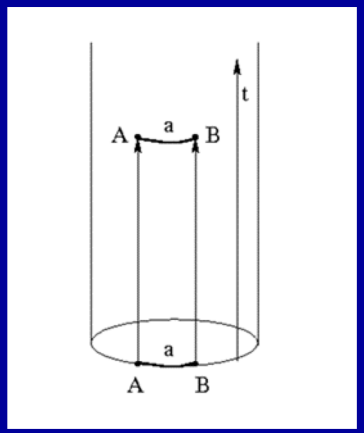
Jean-Pierre Luminet will tell us more about this key-publication

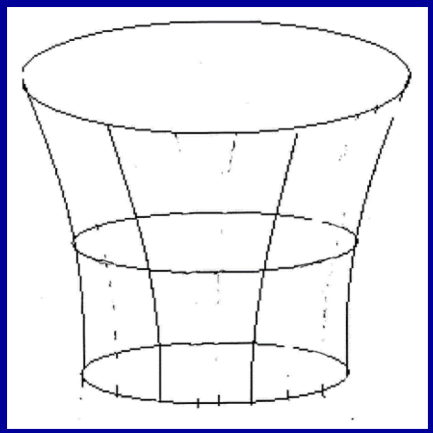
1927 Lemaitre‘s masterstroke:

Un univers homogène de masse constante et de rayon croissant, rendant compte de la vitesse radiale des nébuleuses extra-galactiques.



Annales de la Société scientifique de Bruxelles: $ds^2 = -R(t)^2\, d\sigma^2 + dt^2$





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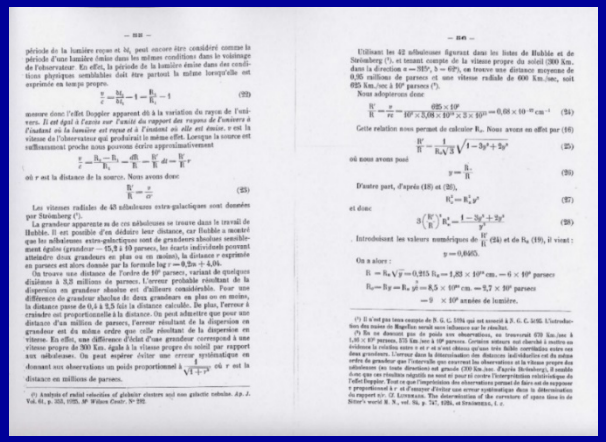

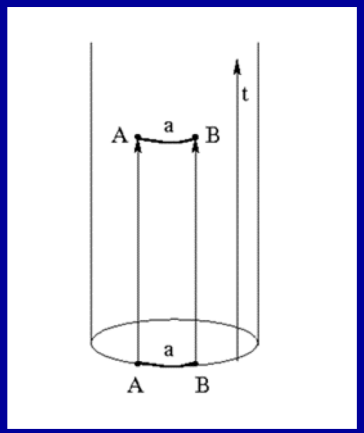

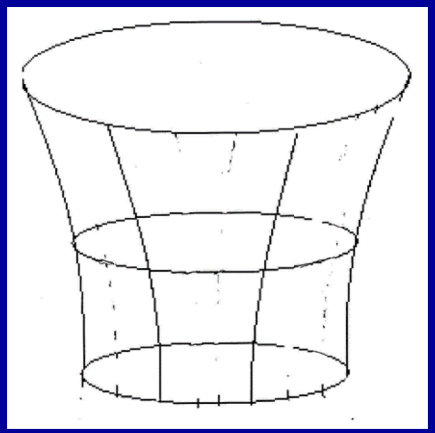

Annales de la Société scientifique de Bruxelles: $ds^2 = -R(t)^2\, d\sigma^2 + dt^2$

Redshifts are due to the expansion of space !

Connection between theory and observation:

In a dynamic universe there is a relation $v = H \cdot r$.

Lemaitre finds H = 575 (km/s)/Mpc.

Einstein tells Lemaître about Friedman 1922:

Über die Krümmung des Raumes.

Hubble‘s contribution of March 1929

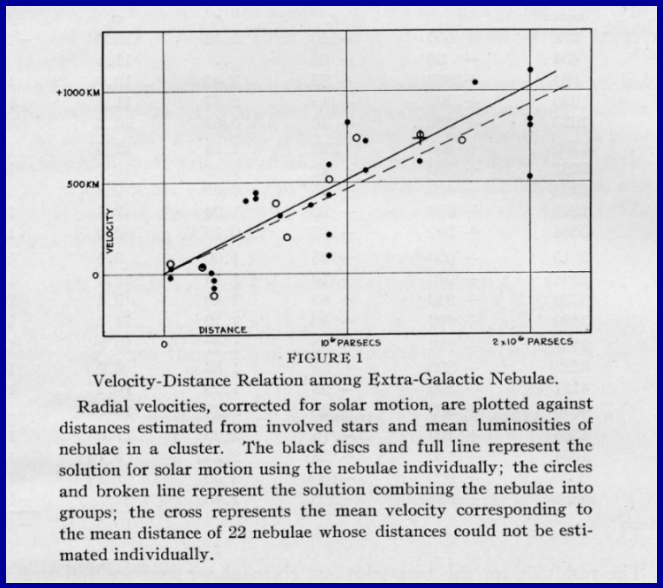

FIGURE 1

Velocity-Distance Relation among Extra-Galactic Nebulae.

Radial velocities, corrected for solar motion, are plotted against distances estimated from involved stars and mean luminosities of nebulae in a cluster. The black discs and full line represent the solution for solar motion using the nebulae individually; the circles and broken line represent the solution combining the nebulae into groups; the cross represents the mean velocity corresponding to the mean distance of 22 nebulae whose distances could not be estimated individually.

From observations Hubble finds: $v = H \cdot r$.

Distances mainly from Hubble,
velocities mainly from Slipher (+ unpublished from Humason).

H= 500 (km/s)/Mpc, Lemaitre in 1927 found H = 575 (km/s)/Mpc.)

+ Humason unpublished
v = 3910 km/s
for N. G. C. 7619

Hubble offered no interpretation for the linear relation, except that *«it may represent the de Sitter effect»*.

First reactions on Hubble's publication

Richard C. Tolman (1881-1948) attempted to explain the redshift by annihilation of matter. This led nowhere.

Zwicky's hypothesis was the photon's loss of energy through gravitational interaction when flying through intergalactic space. This, would result in a wavelength shift to the red.

Neither Hubble, nor Tolman, nor Zwicky suggested that space was expanding !

The breakthrough for the expanding universe

London, Friday, 10 January 1930: Eddington and de Sitter discuss Hubble's 1929 paper.

Eddington: Why should there only be two solutions?

De Sitter: What happens when we put matter into the empty world? The difficulty […] lies in the fact that it is not static.

Discussion published in *The Observatory*, February 1930.

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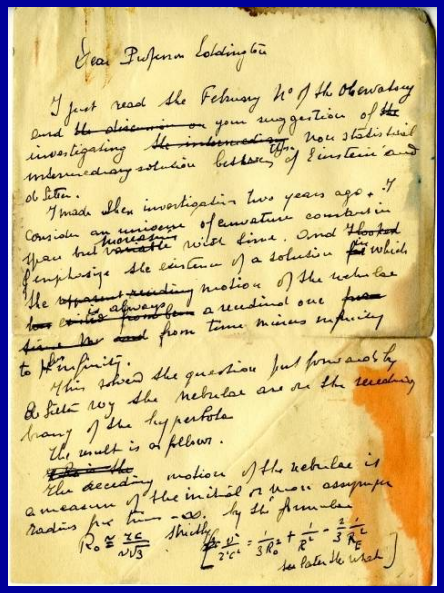
Lemaitre's letter to Eddington in February or March 1930:



Spring 1930:

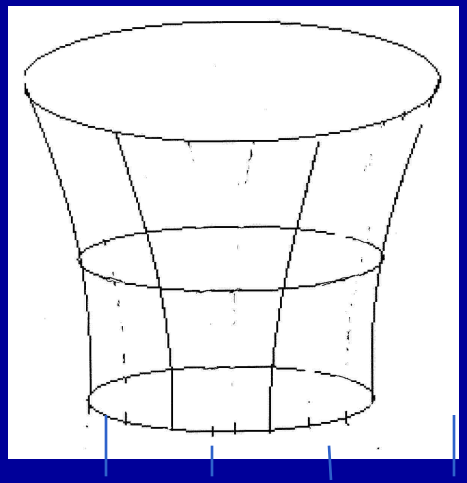
Enthusiastic acceptance by Eddington and de Sitter

Lemaitre made the scales fall from their eyes.

In a unprecedented move *Monthly Notices* published in 1931 a translation of Lemaitre's 1927 publication, with, however, important omissions.

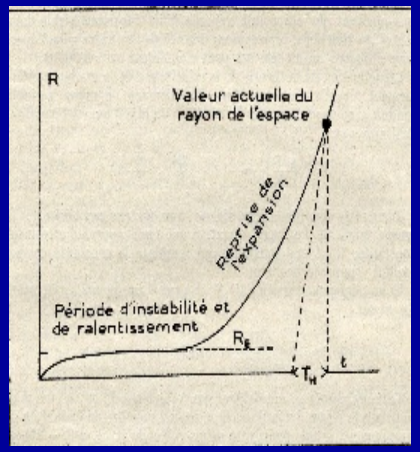
Universe without a beginning, or with a beginning ?

1931: The big bang.



Lemaître's suggestion of 1927: Einstein's model might describe the initial pseudo-static state.

What could cause expansion out of equilibrium? Eddington, McCrea, Mc Vittie, Lemaître 1930.



THE BIG BANG of 1931

Expansion begins through the breaking up of the primeval atom, containing the matter of the whole universe. – Quantum theory to furnish the physics.

Lemaitre 1931 (*Nature*)

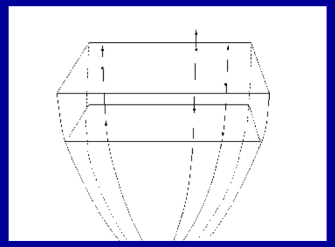
The Einstein-de Sitter universe

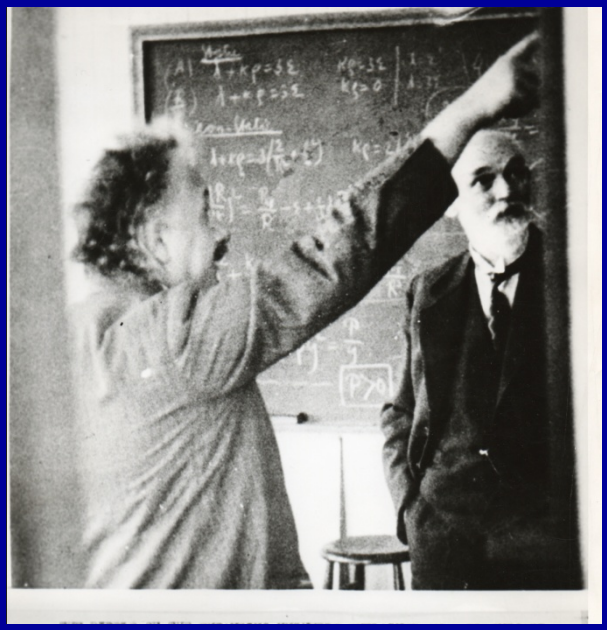
In 1932, Einstein and de Sitter abolish the cosmological constant Λ. They find that an infinite, spatially flat universe satisfies the fundamental equation.
They do not comment on the beginning.

$$G_{ij} - \Lambda g_{ij} = -\kappa\left(T_{ij} - \frac{1}{2} g_{ij} T\right) \quad \rightarrow \quad G_{ij} = -\kappa\left(T_{ij} - \frac{1}{2} g_{ij} T\right)$$

$$ds^2 = -R(t)^2(dx^2 + dy^2 + dz^2) + c^2 dt^2$$

Condition: $\rho_c = \frac{3H^2}{8\pi G}$





Albert Einstein (1879-1955) and Willem de Sitter (1872-1934), Pasadena 1932.

The Einstein-de Sitter universe

In 1932, Einstein and de Sitter abolish Λ and assume a spatially flat universe. They find an expanding solution for a fixed relation between ρ and H.
They do not comment on the beginning.

$$G_{ij} - \Lambda g_{ij} = -\kappa\left(T_{ij} - \frac{1}{2} g_{ij} T\right) \quad \rightarrow \quad G_{ij} = -\kappa\left(T_{ij} - \frac{1}{2} g_{ij} T\right)$$

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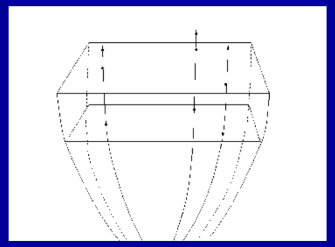
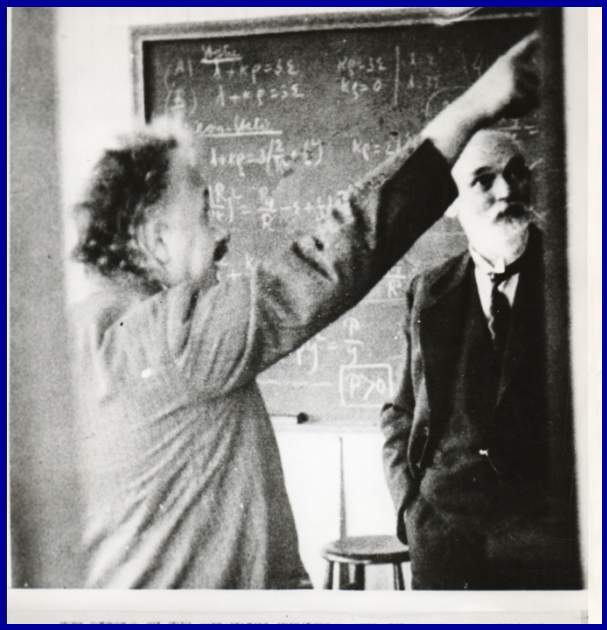




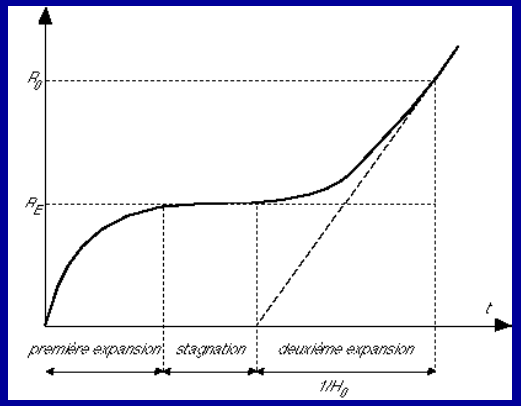
Albert Einstein (1879-1955) and Willem de Sitter (1872-1934), Pasadena 1932.

De Sitter: *The model is more or less compatible with observations; no problem about ρ.*

The Einstein–de Sitter model became accepted cosmology up to near the end of the 20th century.

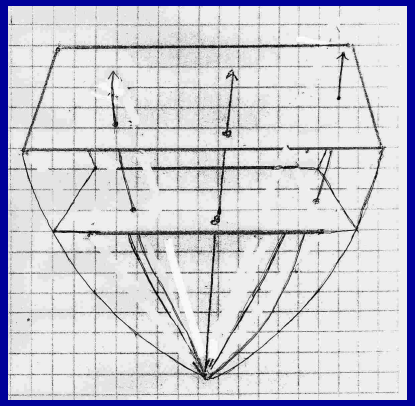
Lemaitre‘s model was relegated into near-oblivion.

Main cosmological models in 1932



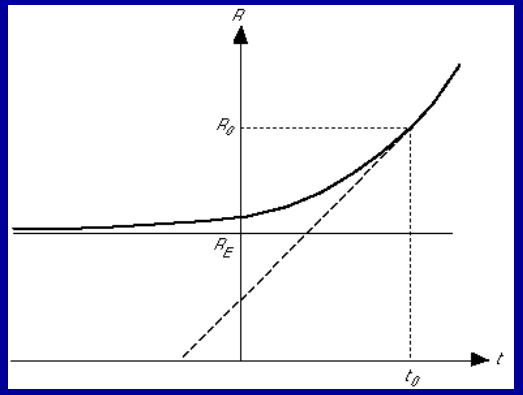
Lemaitre (Λ≠0)

open →



Einstein – de Sitter
(Λ=0)

← closed
↓



Eddington (Λ≠0)

Astronomy in the 1920s

Observers: Extragalactic nebulae and the «de Sitter effect»

Wirtz 1924: Refers to de Sitter 1917; Eddington 1923/24; Redshifts because of
1) flight of objects towards the particle horizon, 2) time moves slower in far away objects.
Distances to the nebulae are unknown. A correlation between the apparent diameters of the spiral nebulae and the observed redshifts seems to exist in the sense predicted by de Sitter.

Silberstein 1924, tried cosmology with globular clusters (no nebular distances available).

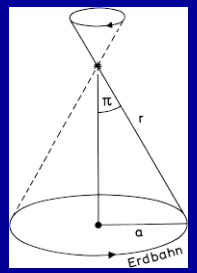
Lundmark 1924, M.N. 84, 747-770. *The determination of the Curvature of Space-Time in de Sitter's World.* We find here the first «Hubble diagram» (distances in units of distance to M 31). The scatter was large, thus with the available data R cannot be determined. Lundmark 1925: Lambert-Charlier cosmology.

Strömberg 1925, Ap.J. 61, 353-362. *Analysis of radial velocities of globular clusters and non-galactic nebulae.*
Contains a list of all the known radial velocities of nebulae and globular clusters without distances. (Lemaître 1927)
Strömberg wants to find:
1) a reference system for the solar motion,
2) is there evidence of a curvature of space-time? Conclusion: No clear evidence.
Distances in units of distance to M 31.

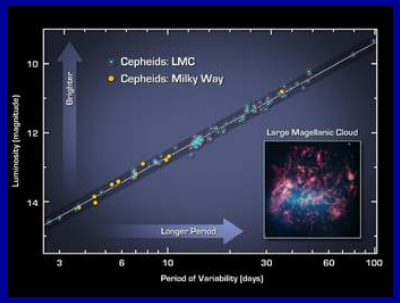
Hubble 1925: Yes, the Island-Universe model is true.
Hubble 1929: For the extragalactic nebulae there is a linear relation $v = H \cdot d$
De Sitter 1930 (B.A.N), 3 publications: Checks on Hubble, rejects Einstein and de Sitter 1917, accepts Lemaître 1927.

Astronomy in the 1920s

Distances, and the structure of the Milky Way



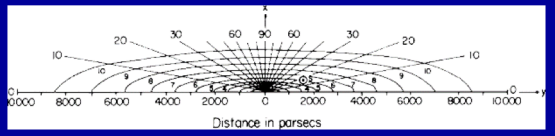
1850s: Bessel, Struve, Henderson: trigonometric parallaxes of stars.



1912 Leavitt: Cepheids in the Magellanic Clouds → period/lluminosity.
≥ 1916 Van Maanen: internal motion in extragalactic nebulae → local objects

1918 Shapley: Cepheids absolute scale. Sun: 20 kpc from galactic centre.
Milky Way ≈100 kpc diameter.
1920 Shapley-Curtis: Great Debate Washington 20.4.1920

1922 Kapteyn's model of the Galaxy: Distribution of stars



Kapteyn 1922

Astronomy in the 1920s

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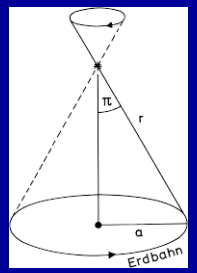

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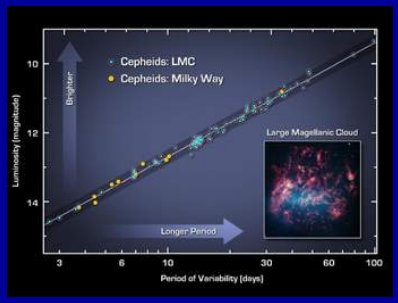

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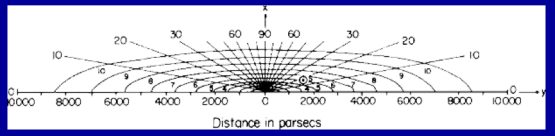
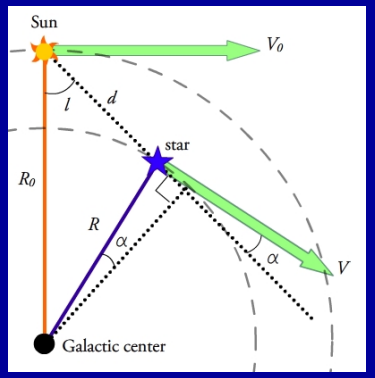


Kapteyn 1922

1922 Kapteyn's model of the Galaxy: Distribution of stars

Shapley, Hubble, Lundmark, Slipher, Wirtz, Strömberg, and many others on distances, apparent and absolute luminosities of stars and nebulae.



1925 Lindblad, *Star-streaming and the structure of the stellar system.*
Motion of subsystems of stars, rotating about the same axis, each subsystem having its own rotation rate and consequent degree of flattening.

1925 Hubble: cepheids in spiral nebulae. → galactic / extragalactic

1927 Jan Oort: differential rotation of the Galaxy (great uncertainties remain).

Astronomy in the 1920s

Spectroscopy

Rutherford 1911: *The Scattering of α and β Particles by Matter and the Structure of the Atom*.
Bohr 1913: On the constitution of atoms and molecules.
Einstein 1916: spontaneous and induced transitions.
Sommerfeld 1919/1923: Atombau und Spektrallinien.
Schrödinger 1926: Schrödinger-Gleichung.
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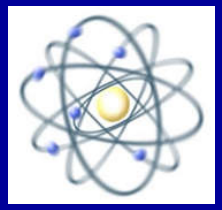

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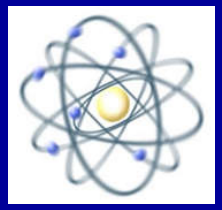


Rutherford 1911

Application of spectroscopy in the 1920s

Spectra of the Sun (photosphere, chromosphere, corona), comets, novae, variable stars, interstellar medium, planetary nebulae, stars, stellar clusters.

Stellar temperatures. Stellar rotation.

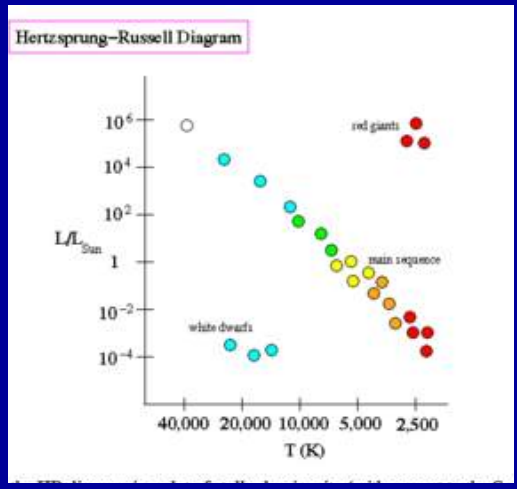
Relative abundances of the elements in stars compared to the Earth.
It was assumed that stars had chemical abundances similar to the Earth.
1925 / 1928 Cecilia Payne, Arnold Unsöld:
H the most abundant element.

Astronomy in the 1920s

Stellar energy, stellar structure and evolution.

1907 Emden: Gaskugeln (classical thermodynamics)
Starting 1907: Hertzsprung-Russell Diagram

Gravitational energy → Nuclear energy
Energy source? Contraction? Annihilation of matter?
From 1905 onwards ($\Delta E = \Delta m \cdot c^2$) in various forms.
1920 Eddington: Fusion of 4 hydrogen atoms into He.
1925 Ed Condon: Annihilation, complete transformation: $\Delta E = \Delta m \cdot c^2$
Motion within the HR-Diagram. Along the Main Sequence from massive to less massive stars?
1939 Bethe finds CNO cycle for $M \geq M_{\odot}$, p-p chain for lighter stars.



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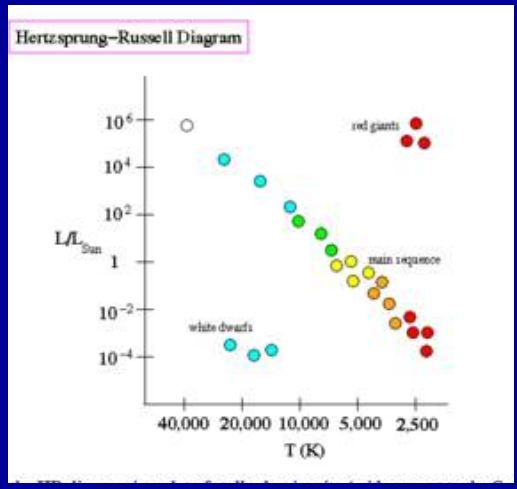

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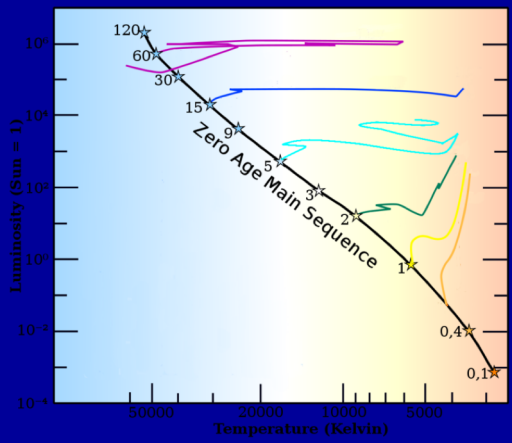


Stellar structure
1916 to 1926 Eddington as the dominant figure.
He introduced Radiation Pressure.
1926 *The Internal Constitution of the Stars.*

Constructing a myth:

«Hubble convinced Einstein that the universe is expanding»

Referring to Einstein's visit to Caltech in January/February 1931 (at the invitation of Milikan)**:**

«Two months with Hubble were enough to pry him loose from his attachment to the cosmological constant." (Topper 2013: Book on Einstein)
"In 1931, Einstein came to Mount Wilson to shake Hubble's hand and thank him for saving relativity from the cosmological constant" (phys.org.news).
"Einstein exclaimed after his Mount Wilson visit: If there is no quasi-static world, then away with the cosmological term!"
(Amir Aczel 2014: *Discover*)
Rubbish: Now found in many other publications, Einstein wrote that 1923 on a postcard to Weyl.

What are the facts about Einstein's conversion?

Eddington 1930: Einstein's universe of 1917 is unstable

June 1930: Einstein stays with Eddington.

Photo taken in Cambridge by Eddington's sister.

May 1930 Eddington (Monthly Notices):

a) He shows explicitly that Einstein's model is unstable.

b) He adopts Lemaitre's model.

June 1930: Einstein visits Eddington.

It was most probably during this visit that Einstein was updated on:

1. **Eddington's finding the instability in Einstein's static model**,
2. the switch of Eddington and de Sitter to Lemaître's expanding universe,
3. Hubble's publication, confirming Lemaitre.

January/February 1931: Einstein in Pasadena at the invitation of Millikan. Close to Tolman. Interested in St. John's solar observations (gravitational redshift). Visits Mount Wilson with Hubble, but doesn't even mention Hubble in his diary. Conversion probably on the way back to Berlin.
(Nussbaumer: European Physics Journal –History,**39,** 37-62 (2014))

Why was Lemaitre nearly forgotten?

1. His modesty and self-effacement.

2. His clinging to the cosmological constant made him appear old-fashioned.

3. Laziness of those writing «history».
   Example: *After Hubble announced his discovery of the expansion of space ...*

4. Efficient advertising of the «Hubble-myth» by interested institutions.

How did Lemaître influence the history of cosmology?

In a lasting way:

1927 Lemaitre discovers the expansion of the universe.

1931 Lemaitre proposes a sudden birth of the expanding univers (the Big Bang).

Essential insights:

1925 He spots de Sitter's ill-chosen coordinates.

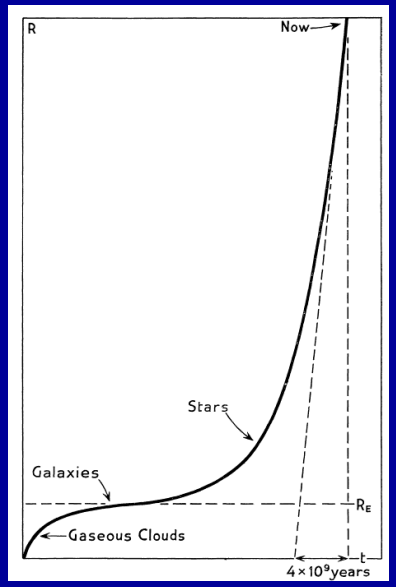
1927 The universe is expanding.

1931 The present universe could have emerged out of pre-existing matter.

1933 He realises that the Schwarzschild singularity is spurious and can be transformed away.

1933 Starts investigation into the emergence of inhomogeneity.

1933 He suggests that the cosmological constant corresponds to vacuum energy, and he defends Λ as a basic force of nature .



De Sitter on Lemaître's contribution to cosmology

Willem de Sitter, talking of the impasse reached in cosmology around 1930:

The way out of this dilemma has been shown by the Abbé Lemaître, whose brilliant solution, the "expanding universe", was discovered by the scientific world about a year and a half ago, three years after it had been published. […] *There can be not the slightest doubt that Lemaître's theory is essentially true, and must be accepted as a very real and important step towards a better understanding of Nature.*

Nature, October 24, 1931:
Contributions to a British Association Discussion on the Evolution of the Universe.

Robertson's spatially homogenous solution of 1928/29

Robertson's line element: $ds^2 = -e^{2\sigma t}(dx^2 + r^2\, d\theta^2 + r^2\, sin^2\theta d\phi^2) + c^2 dt^2$

This is the line element of a dynamic, spatially homogenous universe, eqivalent to the one found by Lemaître. Indeed, in 1929 he states that his universe is dynamic, but that he now will find a transformation «*in order that space-time be stationary*».

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Restricting to cosmologically close objects Robertson found:

$$v = c\,\frac{l}{R}$$

$Lemaître: \quad v = H \cdot l$

Lemaître:
space is expanding

$Robertson: \quad R = c \cdot \frac{l}{v}$

Robertson:
«finding the radius of the observable world»

In a footnote at the end of his 1929 article Robertson mentions that he has become aware of Lemaître 1925